DC Current Sensor

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A current sensor has been developed having capabilities for measuring a differential dc current and also, within a few microseconds, detecting the burst of current caused by a high-voltage arc. This sensor was designed to measure the klystron body current and, in conjunction with a crowbar, protect the tube against internal high-voltage arcs. This article describes the operational characteristics of the current sensor and the results of the characteristics that were investigated.

I. Introduction

When the 100/400-kW transmitters were being developed, it became obvious that a protective device was necessary to guard the RF (body) section of the klystron against serious damage from high-voltage energy; therefore, a crowbar, a device that removes the high voltage in a few microseconds, was designed to protect the klystron. The crowbar needed a signal to gate it *on* whenever an arc (high body current) occurred in the klystron; thus the dc current sensors were developed for this purpose.

The body of the klystron is grounded through its mechanical structure. Because of this, body current is measured by comparing the difference between the cathode current and the collector current (the current leaving the cathode that does not arrive at the collector has been intercepted by the body).

The classical approach to measuring body current is to float the dc power supply using a meter shunt. The output of the shunt then drives an analog body current monitor. The separation of the components on a 64-m-diam antenna makes this approach impractical due to the fast (microsecond) protection requirement of the klystron body. The dc current sensor is now located near the klystron for fast response and the dc power supply is grounded.

One- and two-ampere dc current sensors, models PM1594-1 and PM1594-A2, respectively, have been developed for JPL and have been used in the Deep Space Network for a few years. However, certain abstract characteristics of the current sensors needed additional investigation.

A new procurement was initiated to provide current sensor probes for the DSS 43 and DSS 63 overseas transmitters. Since the newly purchased current sensors had to be tested, the opportunity was seized to make further studies of the current sensor's characteristics. The current sensors have analog and digital outputs that are referred to as the slow and fast outputs, respectively. The fast output has a level control that sets the current level at which the unit will produce a pulse train.

The parameters measured include the slow output linearity and the fast output pulse parameters—rise time, pulse width, pulse amplitude, and, most important, the time delay for the current sensors to produce a pulse after being excited (triggered).

The characteristics investigated include the relationship between the test pulse amplitude and the time delay for various current level settings. Also investigated was the effect on delay time by a test pulse with and without a quiescent current. The test pulse was a 10-microsecond pulse of variable amplitude. It was run through the current sensor with the purpose of triggering the fast output.

II. Current Sensor Operation

The current sensors consist of two units each: a magnetic unit and an electronic unit. The magnetic unit consists of a magnetic core with several coils of wire wound around it—in other words, a magnetic amplifier (MAGAMP). A coaxial high-voltage cable carrying the differential dc current to be measured is passed through the magnetic core and thus is the MAGAMP gate winding. The center conductor carries the cathode current at −70 kVdc, and the shield carries the collector current. The output from this unit is ac, which is rectified and amplified by the electronic unit. This is the analog output of the electronic unit. To achieve fast response, the MAGAMP is excited by a high frequency generated by the electronic unit. The electronic unit will produce a pulse train (Fig. 1) when the current being measured reaches a preset current level set by the fast control. Input and output specifications are listed in Table 1.

III. Slow Output Measurements

The slow output is used to directly drive panel meters to monitor the klystron body current. In order to achieve accuracy, the output must be linear within 5% of full scale. Figure 2 illustrates a typical test result.

IV. Fast Output Measurements

Klystrons operate at very high voltages (−70 kVdc); therefore, they are subject to internal high-voltage arcs that may destroy the tube. The test pulse used in this test simulates the current attributed to an arc. Once triggered the current sensor generates a fast output pulse that goes to the crowbar logic. The crowbar logic is part of a system to protect the klystron (Ref. 1); therefore, the time delay must be minimized.

Figure 3 illustrates the type of test performed. The lower pulse is a test pulse through the current sensor as viewed across a one-ohm resistor. The pulse above it is the fast output pulse which the current sensor produces within 10 microseconds after being triggered. An actual arc will be sensed by the current sensor as a large current pulse. The relatively low current used in this test (15 amperes maximum) was for the purpose of measuring the fast output parameters and also for researching the current sensor's response characteristics.

In the system it is possible for the high-voltage supply to be ON and the body current to vary from a minute amount to as high as 1.25 amperes; therefore, it is possible to have an arc under either of these circumstances. A test was conducted to study the effect on time delay at each of these conditions. The current sensor was fired by a test pulse with and without a quiescent current. The results are discussed in the conclusion.

V. Conclusions

All six of the units tested displayed a linearity within the specifications. The maximum deviation for each unit of full scale from a linear output ranged from 4.62 to 0.42%. The average for this range is 1.78%, which is lower than the design goal of 2%. The average percentage deviation for each unit ranged from 2.71 to 0.28%, and the average for this range is 1.08%.

The output pulse parameters of all the units tested are within the specifications. Typical values are amplitude 18 volts, pulse width 125 microseconds, and rise time 0.4 microseconds.

The time delay varied with the current level setting and test pulse amplitude. Figure 4 illustrates the relationship between the test pulse amplitude and the time delay for various current level settings. From the graph, it can be seen that the time delay is shortest when the fast control is at its lowest possible setting.

There is a limit as to how low the units can be set. The current sensors will produce a pulse train when the dc current being monitored reaches the preset current level;

however, when a current sensor is set below its stable point, the unit may produce a pulse train even though the current being sensed is below the preset level. Most of the units tested become unstable below 0.3 amperes. The actual point of stability varied from 0.5 amperes down to one unit that was completely stable.

The amplitude of the test pulse has an effect on time delay in the following manner: the larger the test pulse, the shorter the time delay. It can be seen in Fig. 4 that for any current level setting as the test pulse increases, the time delay decreases.

The effect on time delay by a test pulse with and without a quiescent current is very small. The difference measures in tenths of microseconds. The shorter time delay occurs when there is a quiescent current present. The presence or absence of a quiescent current has the greatest effect on time delay when the fast control is set low. The effect is then steadily reduced as the current level setting is raised.

The most notable relationship between the test pulse and the current level setting is that even though the fast output will produce a pulse train when the steady-state dc current being monitored reaches the preset current level, it may not do so when a pulse reaches that same preset level. A test pulse of from 1 to 4 amperes greater than the current level setting is required before the current sensor responds. The amount greater than the setting that is required depends on the setting itself and the width of the test pulse. The higher the setting the more current above the setting is needed. The test pulse width used in this test was 10 microseconds wide. A wider pulse reduces the amount of over current required by the current sensor.

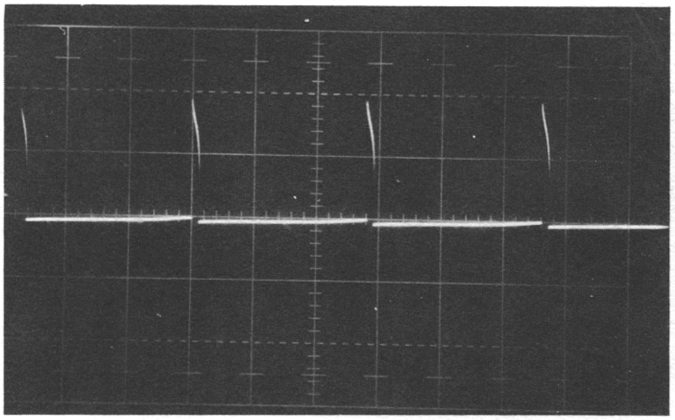
This phenomenon is not detrimental to the protection of the klystron because an arc in the tube will produce a body current of much greater amplitude and width than these test pulses.

Reference

1. Finnegan, E. J., "A New Crowbar Logic Unit," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. VII, pp. 136–138. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1972.

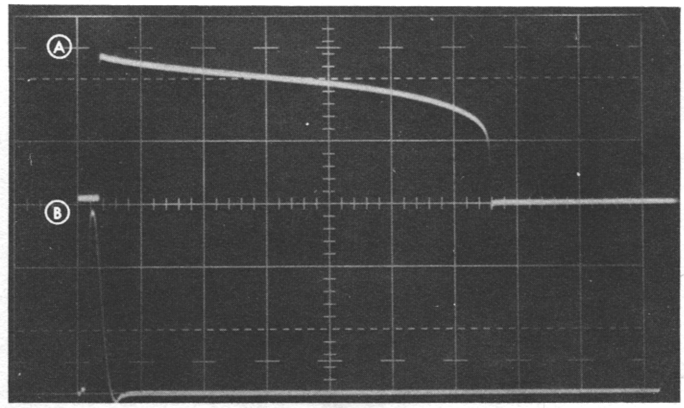
Table 1. Electrical specifications

Input current range:	
Model 1594-1	0 to 1 Adc
Model 1594-A2	0 to 2 Adc
Fast level set:	Capable of producing a pulse at input current level adjustable from:
Model 1594-1	0.5 to 1 A
Model 1594-A2	0.5 to 2 A
Analog output:	
Range	0 to 5 Vdc
Linearity	±5% of full scale over entire range with design goal of ±2%
Ripple	10 mV rms maximum
Load	5 kΩ
Pulse output:	
Amplitude	Design goal of 20 V
Rise time	<1 μs
Time delay	<10 μs with design goal of 1 μs
Load	50 Ω
Power required:	28 Vdc ±5%



PULSE: 10 V/division
TIME: 1 ms/division

Fig. 1. Fast output pulse train



Ⓐ FAST OUTPUT PULSE: 10 V/division
Ⓑ TEST PULSE: 5 V/division
TIME: 20 μs/division

Fig. 3. Test pulse and corresponding fast output pulse

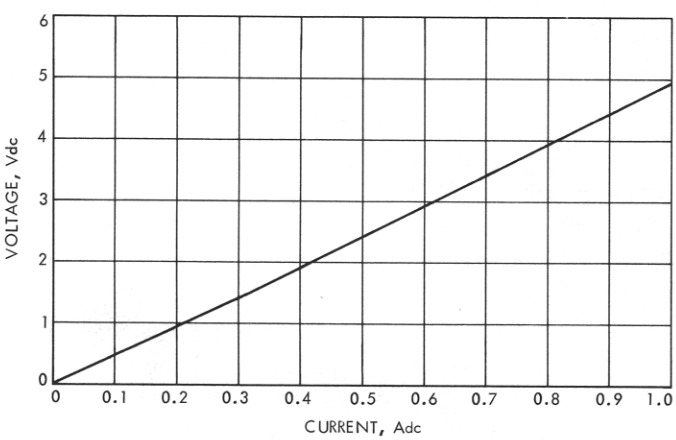


Fig. 2. Graph of slow output linearity

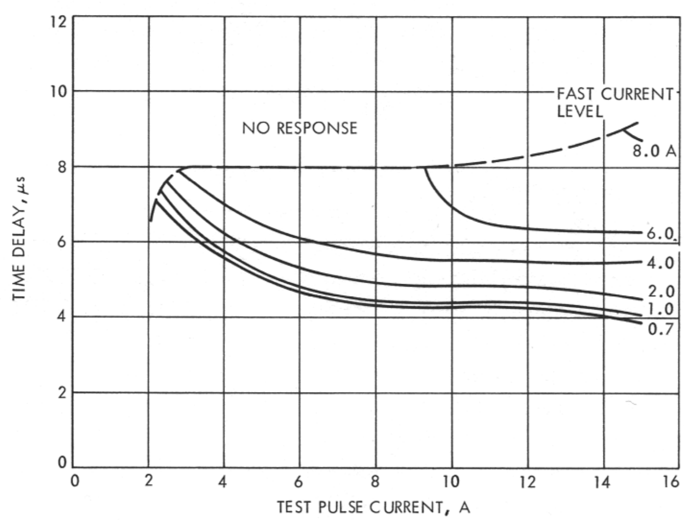


Fig. 4. Graph of time delay vs test pulse amplitude